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SUPERFUND RECORDS

wood downstream to the Mammoth Access, a distance of about 80 km (Czarneski *in ms*). Schmitt and Finger (1982) reported elevated levels of lead, cadmium, and zinc in algae, rooted plants, crayfish, mussels, and fish downstream from the former lead mining area.

We initiated the present study to provide comparable information on heavy metals in riparian vertebrates primarily representing upper trophic levels within the Big River drainage. For comparison, vertebrates were included from the Black River system because it drains part of the "new lead belt," where mining presently occurs (Gale *et al.* 1976). The objectives of the present study were to determine concentrations of lead, cadmium, and zinc in selected vertebrates in the Big and Black River drainages; to compare concentrations based upon proximity to known sources of contamination; and to determine which of the sampled species were the best indicators of metal pollution.

Collections and Methods

Species

Five vertebrate species were selected for study because of their close association with the rivers and their availability: bullfrogs (*Rana catesbeiana*), northern water snakes (*Nerodia sipedon*), green-backed herons (*Butorides striatus*), northern rough-winged swallows (*Stelgidopteryx serripennis*), and muskrats (*Ondatra zibethicus*). In addition, a limited sample of bank swallows (*Riparia riparia*) was collected.

Northern rough-winged swallows and bank swallows were collected by mist net or shotgun, green-backed herons by shotgun, and muskrats by trap or shotgun. Only steel pellets were used in shotgun shells. Bullfrogs were taken by hand or stunned by shooting with .22-caliber rifle cartridges loaded with small steel projectiles; water snakes were collected by shooting at the heads, which were not used in the analyses. In all instances, precautions were taken to prevent contamination from surroundings at time of collection.

Age of green-backed herons, rough-winged swallows, and bank swallows was determined by plumage characteristics as described by Brodkorb (1957). Sex determination of all animals was made by internal examination.

Collection Sites

Animals were collected in 1981–82 at three sites on each river, as well as three auxiliary sites on Big River (Figure 1). Each site extended several km along the rivers in order to permit acquisition of adequate samples.

The first collection site on Big River was near Irondale (Washington County); it extended from the Highway 21 bridge downstream about 20 km. This site was upstream from the "old lead belt" and was not contaminated by mine tailings, as indicated by sediment metal concentrations (Schmitt and Finger 1982). The second site stretched downstream from the tailings pond

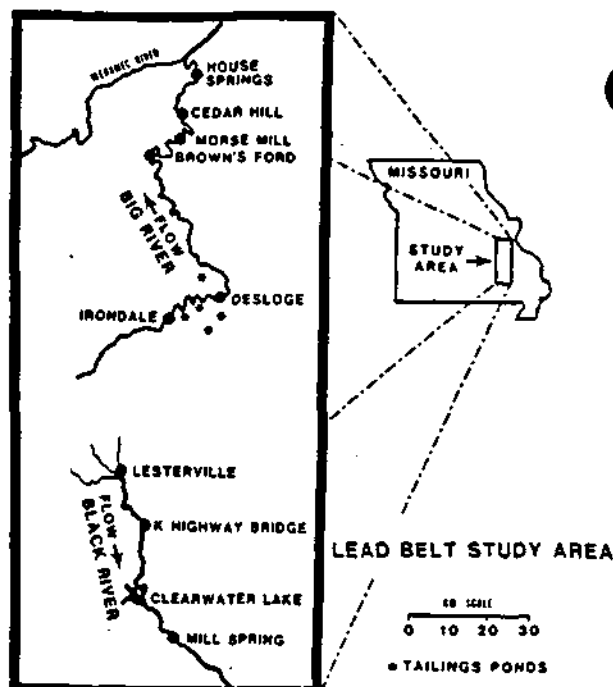


Fig. 1. Lead Belt Study Area. The Big River drains the "old lead belt" and the Black River drains a part of the "new lead belt." (House Springs, Cedar Hill, and Morse Mill were auxiliary sites; all others were main collection sites)

break at Desloge to St. Francois State Park (St. Francois County), a distance of about 15 km. A third site, farther downstream, extended from 17 km above Brown's Ford bridge (Jefferson County) to 10 km below it. Bullfrogs were also collected at three auxiliary point-sites spaced at 18 km intervals downstream from Brown's Ford bridge: Morse Mill, Cedar Hill, and House Springs Access (Jefferson County). Bank swallows were collected from a colony nesting in the face of the tailings pile at Desloge.

The three collection sites on the Black River were: an upper river site, about 26 km long, near Lesterville (Reynolds county); a site on the Black River arm of Clearwater Lake, spanning about 13 km; and a lower river site (Wayne County) extending from 0.4 km below the Clearwater Lake dam downstream 15 km.

Chemical Analysis

Chemical analyses for lead, cadmium, and zinc were conducted by Analytical Bio-Chemistry Laboratories, Inc., Columbia, Missouri. Carcasses of northern rough-winged and bank swallows were analyzed after non-feathered parts, skin, and gastrointestinal tracts were removed; frog carcasses were analyzed after the gastrointestinal tracts were removed; and snake carcasses were analyzed after the skin and gastrointestinal tracts were removed. Only livers (lead and zinc) and kidneys (cadmium) of green-backed herons and muskrats (the largest species) were analyzed, because these tissues are known sites of heavy metal accumulation (White and Finley 1978; Hutton and Goodman 1980; Eastin *et al.* 1983; Erickson and Lindzey 1983).

All samples were prepared for analysis by nitric acid digestion. While the entire kidney was digested for sampling only 2.5–4.5 g portions of livers were used following homogenization by hand

Table 1. Number of animals collected during 1981-82 on the Big River and Black River, Missouri, by species and site

River and site	Species							Total
	Green-backed heron		Bullfrog	Northern water snake	Northern rough-winged swallow		Muskrat	
	Adult	YOY ^a			Adult	YOY		
Big River								
Irondale	15	3	15	15	15	4	10	77
Desloge	15	1	15	15	15	—	5	66
Brown's Ford	15	5	15	14	3	6	1	59
Desloge tailings pile	—	—	—	—	5 ^b	5 ^b	—	10
Morse Mill	—	—	5	—	—	—	—	5
Cedar Hill	—	—	5	—	—	—	—	5
House Springs	—	—	5	—	—	—	—	5
Black River								
Upper River	15	3	15	11	15	5	2	66
Clearwater	15	5	15	10	15	5	6	71
Lower River	15	4	15	15	4	4	4	61
Total	90	21	105	80	72	29	28	425

^a YOY = young of year^b Bank swallows

Table 2. Metal levels in liver (Pb and Zn) and kidneys (Cd) of green-backed herons collected in the Big and Black River drainages of southeastern Missouri, 1981-82

River and collection site	Metal concentrations, ppm wet weight		
	Lead (liver)	Cadmium (kidneys)	Zinc (liver)
Big River			
Irondale	0.09 ^a (6/18) ^b ND-0.26 ^{c,d}	0.35 (14/18) ND-1.10	31.5 (18/18) 24.3-40.4
Desloge	0.47 (15/16) ND-1.47	0.98 (15/15) 0.13-5.70	33.1 (16/16) 19.8-45.0
Brown's Ford	0.55 (20/20) 0.15-0.97	1.13 (20/20) 0.13-4.30	30.5 (20/20) 23.0-39.5
Black River			
Upper River	0.07 (4/18) ND-0.16	0.65 (17/18) ND-1.90	33.2 (18/18) 24.7-51.3
Clearwater Lake	0.08 (5/20) ND-0.21	0.35 (13/19) ND-1.20	27.7 (20/20) 16.1-42.6
Lower River	0.07 (2/19) ND-0.25	0.50 (16/19) ND-1.10	27.8 (19/19) 20.4-38.0

^a Geometric mean^b Numbers in parentheses are numbers of samples containing detectable residues/total numbers of samples analyzed^c Range^d ND = not detected

in plastic bags. Bullfrogs and larger snakes were put through a meat grinder twice and 2.5-3.5 g samples were used. Swallows and small snakes were homogenized in a blender and 6.5-10 g aliquots were taken for digestion. All samples regardless of weight were weighed into 100 ml precleaned micro Kjeldahl

flasks. An appropriate volume of double-distilled nitric acid (20-30 ml) was added to each flask. Prewashed boiling chips were added and the flasks placed on a micro Kjeldahl digestion apparatus set on low heat. After the initial reaction subsided, the heat was increased. Samples were then digested to a volume of

Table 3. Metal levels in liver (Pb and Zn) and kidneys (Cd) of muskrats collected in the Big and Black River drainages of southeastern Missouri, 1981-82

River and collection site	Metal concentrations, ppm wet weight		
	Lead (liver)	Cadmium (kidneys)	Zinc (liver)
Big River			
Irondale	0.16 ^a (7/10) ^b ND-0.32 ^{c,d}	0.18 (6/10) ND-0.65	25.4 (10/10) 19.6-39.6
Desloge	0.69 (5/5) 0.29-1.60	2.19 (5/5) 0.13-5.30	29.1 (5/5) 23.0-35.2
Brown's Ford	0.64 (1/1) — ^d	1.70 (1/1) —	31.1 (1/1) —
Black River			
Upper River	0.17 (1/2) ND-0.31	0.59 (2/2) 0.10-1.30	25.3 (2/2) 25.0-25.6
Clearwater Lake	0.07 (2/6) ND-0.14	0.14 (5/6) ND-0.29	25.5 (6/6) 19.7-29.8
Lower River	0.26 (3/4) ND-0.53	0.19 (4/4) 0.14-0.24	26.9 (4/4) 24.6-33.1

^a Geometric mean^b Numbers in parentheses are numbers of samples containing detectable residues/total numbers of samples analyzed^c Range^d ND = not detected; — = not applicable

1-2 ml. If necessary, additional acid was added to complete digestion. The samples were again heated on medium heat until a low volume (1-2 ml) was reached. Upon completion of digestion, the samples were allowed to cool, then quantitatively transferred to 50 ml volumetric flasks using deionized water. The solutions were mixed and analyzed. Blanks were handled in the same manner. Metal concentrations for contamination blanks derived from the digestion process were within the following ranges: cadmium 0.0007 to 0.005 µg/ml, lead 0.005 to 0.015 µg/ml, and zinc 0.007 to 0.02 µg/ml.

Cadmium concentrations were determined by inductively coupled argon plasma spectroscopy (Jarrell-Ash Model 800 Series Atom Comp; mention of a specific product does not constitute government endorsement). This instrument was equipped with a spectrum shifter which corrected for background on one side of each analytical line. All instrument settings were those recommended by the manufacturer. Zinc was determined either by inductively coupled argon plasma spectroscopy, with methods similar to those for cadmium, or by atomic absorption spectrophotometry. The instrument settings for atomic absorption determination of zinc concentrations were those recommended by the manufacturer. Lead concentrations were determined by atomic absorption spectrophotometry, either by graphite furnace or flame atomic absorption, depending on the concentration of lead in each sample. Instrumentation included a Perkin-Elmer 305B spectrophotometer with background correction and an HGA-2100 graphite furnace. The instrument settings were those recommended by the manufacturer. The limit of detection of all analyses was 0.1 ppm (µg/g) wet weight. The average recovery of samples spiked prior to digestion for each metal was: lead, 104% (23 samples); cadmium, 87% (28 samples); and zinc, 99% (28 samples). Residues were not corrected for percent recovery.

Each value reported is the average of two determinations except for samples in which no residues could be discerned; value of one-half the lower limit of detection were then provided. Geometric means were calculated. Statistical analyses (ANOVA) were performed on log (value + 1) transformed data because the variances were proportional to the means.

Results

During the 1981 and 1982 field seasons, 424 animals were collected (Table 1). No age or sex distinction was made in analyzing metal concentrations in any of the species collected because small sample sizes precluded statistical comparisons.

Geometric means (\bar{X}_g) of lead, cadmium, and zinc concentrations for each species at each site are presented in Tables 2-6. A copy of the raw data from the analyses of each sample, including collection site, age, sex, weight, and metal residues detected, may be obtained from the Fish and Wildlife Reference Service, operated by Informatics General Corporation, 1776 E. Jefferson St., Rockville, MD 20852 by requesting "Supplementary data for concentrations of lead, cadmium, and zinc in wildlife of the Big River and Black River drainages in southeast Missouri" by K. R. Niethammer, R. D. Atkinson, T. S. Baskett, and F. B. Samson. Included in these supplemental data are concentra-

Table 4. Metal levels in northern rough-winged swallows (carcasses) collected in the Big and Black River drainages of southeastern Missouri, 1981-82

River and collection site	Metal concentrations, ppm wet weight		
	Lead	Cadmium	Zinc
Big River			
Irondale	0.51 ^a (13/18) ^b ND-5.40 ^{c,d}	0.08 (4/19) ND-0.40	32.00 (19/19) 26.2-42.6
Desloge	1.86 (10/12) ND-14.7	0.14 (11/12) ND-0.24	30.9 (12/12) 27.2-36.3
Brown's Ford	0.44 (6/8) ND-1.80	0.11 (5/9) ND-0.19	32.1 (9/9) 27.8-36.5
Black River			
Upper River	2.39 (17/20) ND-61.2	0.09 (8/20) ND-0.28	29.6 (20/20) 23.6-45.2
Clearwater Lake	1.11 (15/19) ND-5.90	0.12 (11/20) ND-0.42	30.4 (20/20) 25.0-34.0
Lower River	0.23 (3/8) ND-1.40	ND (0/8) — ^d	25.8 (7/7) 20.8-35.0

^a Geometric mean^b Numbers in parentheses are numbers of samples containing detectable residues/total numbers of samples analyzed^c Range^d ND = not detected; — = not applicable

tions of barium, manganese, iron, and copper for four individuals of each species from each main collection site.

Lead

Northern water snakes, bullfrogs, green-backed herons, and muskrats contained significantly higher lead concentrations at collection sites downstream from the "old lead belt" than at the uncontaminated site on the Big River (Irondale) or Black River sites (ANOVA, $P < 0.05$) (Figure 2). Concentrations in northern rough-winged swallows varied between sites without a defined pattern. Ten bank swallows (five adults and five flightless immatures) collected from the Desloge nesting colony contained lead concentrations ranging from 2.0 to 39.1 ppm ($\bar{X}_g = 9.8$ ppm). These concentrations were significantly higher than those of northern rough-winged swallows at any of the collection sites (Mann-Whitney U Test, $P < 0.05$).

Compared to other species examined, bullfrogs had the highest lead concentrations. Bullfrogs from four of the five collection sites downstream from the tailings source at the "old lead belt" contained similar mean lead levels; bullfrogs collected at

Morse Mill contained much higher lead concentrations (Table 6). We reanalyzed samples from bullfrogs at Morse Mill and the neighboring Cedar Hill and House Springs sites. No significant differences were found between means of the duplicate analyses and the original means (Mann-Whitney U Test, $P > 0.10$). Geometric mean lead levels for the second analyses were 107.5 ppm for Morse Mill, 12.7 ppm for Cedar Hill, and 11.6 ppm for House Springs. We cannot explain the elevated lead concentrations in the Morse Mill bullfrogs.

Cadmium

Bullfrogs, green-backed herons, and muskrats contained higher cadmium concentrations at collection sites downstream from the source of metal contamination than at the Big River control site (Irondale) and the three Black River collection sites (ANOVA, $P < 0.05$) (Figure 2). Cadmium was detected in only one northern water snake, a specimen collected from Brown's Ford on the Big River. Cadmium concentrations in northern rough-winged swallows varied from site to site with no noticeable trends. Seven of the ten bank swallows collected from the Desloge nesting colony contained detectable cad-

Table 5. Metal levels in northern water snakes (carcasses) collected in the Big and Black River drainages of southeastern Missouri 1981-82

River and collection site	Metal concentrations, ppm wet weight		
	Lead	Cadmium	Zinc
Big River			
Irondale	0.19 ^a (11/15) ^b ND-0.64 ^{c,d}	ND (0/15) — ^d	29.0 (15/15) 18.4-42.6
Desloge	6.07 (15/15) 1.60-13.0	ND (0/15) —	37.6 (15/15) 26.9-63.2
Brown's Ford	7.52 (12/12) 2.40-14.1	0.06 (1/14) ND-0.12	37.1 (14/14) 23.9-46.2
Black River			
Upper River	1.21 (10/11) ND-3.90	ND (0/11) —	37.2 (11/11) 27.9-51.3
Clearwater Lake	0.97 (10/10) 0.20-3.80	ND (0/10) —	36.4 (9/9) 28.1-42.0
Lower River	0.15 (8/15) ND-0.55	ND (0/15) —	31.6 (15/15) 19.7-47.0

^a Geometric mean^b Numbers in parentheses are numbers of samples containing detectable residues/total numbers of samples analyzed^c Range^d ND = not detected; — = not applicable

mium concentrations, ranging up to 0.48 ppm, \bar{X}_g = 0.19 ppm.

Zinc

Bullfrogs contained significantly higher zinc levels at collection sites downstream from the source of metal contamination than at the other sites (ANOVA, $P < 0.05$) (Figure 2, Table 6). Zinc concentrations in muskrats may have followed the same pattern, but because of small sample sizes no statistical comparisons were made between mean zinc levels at the different sites. Concentrations in northern water snakes were significantly higher at the two sites below the former lead mining area than at Irondale, the uncontaminated site on Big River (ANOVA, $P < 0.05$); however, snakes from the upper Black River and Clearwater Lake contained zinc levels comparable to those of snakes collected below the source of metal contamination. Mean zinc levels in green-backed herons and rough-winged swallows collected below the "old lead belt" did not differ significantly from those collected at Irondale (ANOVA, $P > 0.05$). Bank swallows from the Desloge nesting colony contained

zinc concentrations between 28.8 and 53.5 ppm; \bar{X}_g was 36.4 ppm.

Discussion

Data from the present study support the findings of Schmitt and Finger (1982) and Whelan (1983) showing that metals from tailings eventually find their way into the biota downstream from the former lead mining area. Bullfrogs, muskrats, and green-backed herons collected downstream from the source of metal contamination at Desloge on the Big River contained elevated levels of lead and cadmium compared to specimens collected at the uncontaminated site upstream from Desloge and those collected on the Black River. Northern water snakes also contained elevated lead levels downstream from Desloge; however, northern water snakes apparently did not accumulate cadmium. Bullfrogs and muskrats collected at sites downstream from the source of contamination contained elevated zinc levels compared to specimens collected upstream and at the Black River sites. Differences in zinc concentrations of the other species collected from contaminated and uncontaminated sites were less apparent and not significant. This

Table 6. Metal levels in bullfrogs (carcasses) collected in the Big and Black River drainages of southeastern Missouri, 1981-82

River and collection site	Metal concentrations, ppm wet weight		
	Lead	Cadmium	Zinc
Big River			
Irondale	0.97 ^a (14/14) ^b 0.11-6.10 ^{c,d}	ND (0/15) — ^d	20.9 (15/15) 15.5-28.4
Desloge	13.5 (15/15) 3.50-31.0	0.31 (13/15) ND-0.89	42.7 (15/15) 29.8-64.5
Brown's Ford	14.0 (15/15) 2.90-41.0	0.26 (12/15) ND-0.64	29.9 (15/15) 20.5-37.5
Morse Mill	109.0 (5/5) 21.0-300.0	0.20 (5/5) ND-0.45	35.6 (5/5) 30.8-52.0
Cedar Hill	12.6 (5/5) 5.30-69.6	0.28 (5/5) 0.13-0.42	31.3 (5/5) 23.8-42.5
House Springs	14.9 (5/5) 5.30-69.6	0.24 (4/5) ND-0.46	29.5 (4/4) 24.1-38.0
Black River			
Upper River	1.47 (15/15) 0.18-4.90	ND (0/15) —	22.3 (15/15) 14.9-59.4
Clearwater Lake	1.31 (14/15) ND-3.30	ND (0/15) —	22.6 (15/15) 15.3-35.8
Lower River	1.22 (14/15) ND-7.40	ND (0/15) —	21.9 (15/15) 17.5-32.9

^a Geometric mean^b Numbers in parentheses are numbers of samples containing detectable residues/total numbers of samples analyzed^c Range^d ND = not detected; — = not applicable

finding could reflect the essentiality of zinc, with homeostatic mechanisms reducing the variation of tissue levels (Fisher 1975).

Comparisons with Results of Other Studies

In general, the values for lead, cadmium, and zinc concentrations in bullfrog carcasses collected downstream from the former lead mining area were greater than concentrations reported in bullfrog carcasses from streams draining agricultural, forested, and municipal-industrial watersheds in Alabama (Hill *et al.* 1983). For example, the mean lead concentration in bullfrogs from the most polluted of three watersheds in the Alabama study was 1.1 ppm (wet weight), which compares closely with levels in the uncontaminated site on Big River (0.97 ppm, wet weight) and is less than one-tenth of the mean levels at all contaminated sites in the present study. Cadmium levels in bullfrog carcasses from our con-

taminated sites were four to five times greater than those from the most polluted Alabama watershed. Zinc levels were 1.5-2 times those of the Alabama study.

Mean lead concentrations in livers (0.6-0.7 ppm, wet weight) of muskrats collected from the Big River downstream from Desloge were less than liver concentrations (3.7-5.2 ppm, wet weight) reported in muskrats collected from a Pennsylvania marsh that is a mixing area and passageway for pollutants from residential, industrial, recreational, and commercial developments (Erickson and Lindzey 1983). Mean concentrations of cadmium in kidneys of contaminated Big River muskrats (1.7-2.2 ppm, wet weight) were greater than those in kidneys of the Pennsylvania muskrats (0.1-0.2 ppm, wet weight).

Livers of prefledgling black-crowned night-herons (*Nycticorax nycticorax*) from three Atlantic Coast sites receiving metals from effluent, sludge, or industrial wastes contained mean zinc concen-

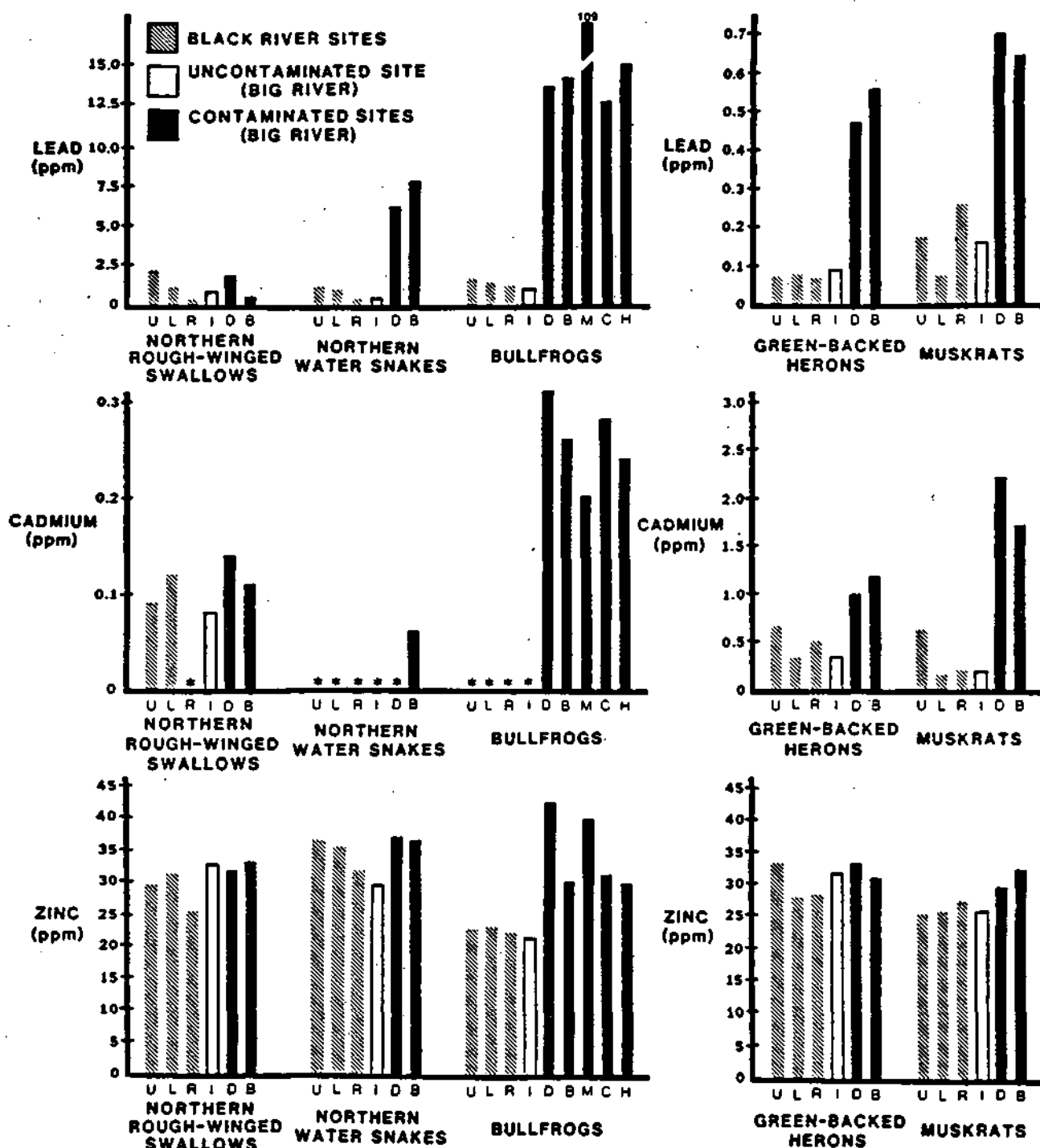


Fig. 2. Geometric mean lead, cadmium, and zinc concentrations (ppm, wet weight) in five vertebrate species from the lead belt area of Missouri, 1981-82. Metal levels in green-backed herons and muskrats are reported for livers (Pb and Zn) and kidneys (Cd); levels in the other three species are reported for carcasses. Collection sites are abbreviated as follows: U = upper Black River, L = Clearwater Lake, R = lower Black River, I = Irondale, D = Desloge, B = Brown's Ford, M = Morse Mill, C = Cedar Hill, and H = House Springs Access. * = none detected

trations of 503-649 ppm, dry weight (Custer and Mulhern 1983). These levels were much higher than those in livers of green-backed herons collected from the tailings-contaminated portions of the Big

River (about 98-107 ppm dry weight, based on 69% moisture content to convert from wet weight). Kidneys of every green-backed heron collected downstream from the old lead mining area in Missouri

contained cadmium; whereas livers of only 3 of 55 prefledgling black-crowned night-herons collected by Custer and Mulhern (1983) contained detectable cadmium concentrations; detection limits (0.1 ppm) were identical in the two studies. Mean lead concentrations in livers of black-crowned night-herons were 0.83–1.24 ppm (dry weight) in the Atlantic coast study and about 1.5–1.8 ppm (dry weight) in livers of green-backed herons from contaminated sites in the present study. Hoffman and Curnow (1973) did not detect cadmium or lead in livers of immature and adult great blue herons (*Ardea herodias*), black-crowned night-herons, or great egrets (*Casmerodius albus*) from two Lake Erie colonies near outfall of sewage and industrial wastes.

Metal Concentrations Related to Trophic Level

Concentrations of heavy metals such as lead and zinc decrease with increasing trophic level in marine food-chains (I.D.O.E. 1972). Lead concentrations decreased markedly with an increase in trophic level in both detritus-based and grazing food-chains in dredge-spoilpond ecosystems (Drifmeyer and Odum 1975). Data from the present study also show that these metals do not readily biomagnify, as animals of upper trophic levels did not contain higher lead and cadmium concentrations than those of lower trophic levels. For example, lead and cadmium levels in livers and kidneys of piscivorous green-backed herons (Niehammer *et al.* 1983) were lower than those in muskrats which are primarily herbivorous (Shanks 1947). Lead and cadmium levels in bullfrogs, which are omnivorous (Korschgen and Baskett 1963) were higher than those in the piscivorous (Mushinsky and Hebrard 1977) northern water snake. Schmitt and Finger (1982) reported higher lead and cadmium concentrations in the benthic-feeding redhorse than in the predatory smallmouth bass (*Micropterus dolomieu*). They reported the following concentration gradient for lead levels in the biota they sampled at sites located downstream from Desloge on the Big River: attached algae > water willow > mussels > crayfish > fish. This concentration gradient was similar for cadmium except that mussels contained the highest concentrations. Instead of metals being biomagnified with increasing trophic levels, apparently animals most closely associated with the metal-rich river sediment contain the highest lead and cadmium concentrations.

Whelan (1983) reported that metals in the water were probably not a major contributor to concentrations in the biota of Big River because the waters are highly buffered, hard, have a high pH, and a

high specific conductance. Schmitt and Finger (1982) found that most of the metals derived from lead mine tailings are transported in the solid phase. These findings help explain the high metal concentration in organisms associated with sediment.

Bank Swallows

Ten bank swallows collected from the Desloge colony had much higher lead and cadmium levels than northern rough-winged swallows nesting in natural rock ledges along Big River. Both species feed primarily by capturing insects in flight (Bent 1942). The bank swallows, by nesting in the tailings pile, were more closely associated with the metal-laden tailings than the northern rough-winged swallows. The tailings in this area contain lead concentrations that range from 2,360 ppm, dry weight to 26,600 ppm and cadmium concentrations from 8 ppm to 158 ppm (Kramer 1976). Respiratory and dermal exposure to tailings dust could explain the elevated metal levels in the bank swallows. The bank swallows may have ingested the metals while preening feathers that had come into contact with the metal-laden tailings. Some contamination from tailings dust in feathers when the carcasses were skinned is also a possibility.

Species Suitable for Monitoring Metal Contamination

Our study provided an opportunity to evaluate five vertebrates as potential monitors of heavy metal contamination. A good monitoring organism should accumulate pollutants in levels representative of the degree of contamination without dying, be relatively sedentary, ubiquitous, long lived, and easily collected. The availability of good monitoring organisms would reduce the number of samples needed to evaluate levels of metal contaminants, to identify problem areas, and to evaluate the fate of these contaminants.

Northern rough-winged swallows were of little value as monitoring organisms for metals; concentrations in their carcasses varied from site to site, possibly owing to their high mobility. Northern water snakes accumulated little or no cadmium and thus would not be an acceptable monitoring species. Lead (in liver) and cadmium (in kidney) concentrations in green-backed herons and muskrats indicated the contamination problem downstream from the "old lead belt"; thus these two species could be of some value in monitoring programs. Bullfrogs contained the highest concentrations of

Table 7. Metal concentrations in composite samples of selected tissues of five bullfrogs collected at the Desloge site on Big River, Missouri, 1982

Tissue	Metal concentrations, ppm wet weight		
	Lead	Cadmium	Zinc
Liver	6.30	5.00	49.3
Kidney	— ^a	40.70	36.6
Muscle	1.70	ND ^b	12.7
Brain	3.00	0.10	18.4
Skin	4.30	ND	109.0
Carcass	30.50	0.32	58.1

^a — = no data reported

^b ND = not detected

lead and zinc, and clearly illustrated elevated levels of lead, cadmium, and zinc downstream from the source of metal contamination. Metals in bullfrogs were concentrated in most tissues, not just the skins (Table 7). Bullfrogs seemed to be the best monitoring species for metals we studied. The bullfrog is widely distributed in North America (Conant 1975); relatively sedentary, seldom moving more than 1 km within a single season (Raney 1940; Ingram and Raney 1943; Willis et al. 1956); and easily collected. Although bullfrogs seem to be good monitoring organisms for trace metal contamination, other studies have shown that they are not desirable as monitors of organochlorine pesticide contamination, because they do not accumulate these residues in proportion to environmental concentrations (Meeks 1968; Niethammer et al. 1984). Frogs have a high rate of turnover or renewal of fatty acids (Brown 1964), which might increase organochlorine residue mobilization and excretion. A study by Hill et al. (1983) also demonstrated this dichotomy between residue levels of organochlorine and heavy metal contaminants in bullfrogs. In their study, lead concentrations in bullfrogs were greater than those in cottonmouths (*Agkistrodon piscivorus*), raccoons (*Procyon lotor*), and river otters (*Lutra canadensis*); conversely bullfrogs contained the lowest organochlorine residues detected among these species.

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